

CLAIMS

What is claimed is:

1. A method of rate control between a first communication
5 terminal and one or more remote communication terminals of a
communication system, the method comprising:

receiving, at each of the one or more remote communication
terminals, a respective signal modulated using a respective one of a plurality
of rates from the first communication terminal via a respective forward
10 channel, wherein each communication terminal is capable of supporting
communications using the plurality of rates; and

determining a respective optimal one of the plurality of rates to
be used by the first communication terminal for a respective subsequent
signal to be transmitted to each of the one or more remote communication
15 terminals based upon a respective maximization of the throughput to each of
the one or more remote communication terminals given a respective channel
state of each respective forward channel and a cost associated with a change
in rate.

- 20 2. The method of Claim 1 wherein the determining step
comprises:

determining, for each determining the respective optimal one
step, respective cost functions corresponding to selecting each of the plurality
of rates for the respective subsequent signal given the respective received
25 signal using the respective one of the plurality of rates, each of the respective
cost functions being a function of the throughput to a respective one of each
of the one or more remote communication terminals and a cost associated
with the change in rate; and

selecting, for each determining the respective optimal one step, a
30 respective optimal cost function from the respective cost functions, the

respective optimal cost function providing the respective optimal one of the plurality of rates to be used by the first communication terminal for the respective subsequent signal to be transmitted by the first communication terminal.

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3. The method of Claim 2 wherein the determining, for each of the determining the respective optimal one step, the respective cost functions step comprises:

10 determining, for each of the determining the respective optimal one step, respective cost functions associated with arriving at a system state using the respective one of the plurality of rates from previous system states using each of the plurality of rates, each of the respective cost functions being a function of the throughput to a respective one of each of the one or more remote communication terminals and the cost associated with the change in rate;

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wherein the selecting, for each determining the respective optimal one step, the respective optimal cost function comprises:

20 selecting, for each determining the respective optimal one step, the respective optimal cost function from the respective cost functions, the respective optimal cost function providing an optimal one of the plurality of rates used in arriving to the system state using the respective one of the plurality of rates; and

25 equating the optimal one of the plurality of rates used in arriving to the system state to the respective optimal one of the plurality of rates to be used by the first communication terminal for the subsequent signal.

4. The method of Claim 2 further comprising solving, for each of the one or more remote communication terminals, the following equation to perform the determining, for each determining the respective optimal one step, the respective cost function step and the selecting, for each determining the respective optimal one step, the optimal cost function step:

$$V_n(s_n, r_n) = \max_{u \in \{1, 2, \dots, L\}} \{R(s_n, r_n, u) + \beta V_{n-1}(s_n, u)\}$$

- where $V_n(s_n, r_n)$ is the respective optimal cost function for the n^{th} iteration, s_n is a current channel state of the respective forward channel corresponding to the respective received signal, r_n is the respective one of the plurality of L rates that the respective received signal is modulated with, u assumes any possible value of the plurality of L rates for the rate r_{n+1} , r_{n+1} is the respective optimal one of the plurality of L rates to be used by the first communication terminal for the respective subsequent signal, β is a discount factor, $V_{n-1}(s_n, u)$ is the respective optimal cost function for iteration $n-1$, and $R(s_n, r_n, u)$ is a cost-per-stage function given by:

$$R(s_n, r_n, u) = \begin{cases} T(r_n, s_n) & \text{if } u = r_n \\ C + T(u, s_n) & \text{if } u \neq r_n \end{cases}$$

- where $T(r_n, s_n)$ is the throughput to a respective one of the one or more remote communication terminals when rate r_n is used for r_{n+1} given channel state s_n , $T(u, s_n)$ is the throughput to the respective one of the one or more remote communication terminals when rate u is used for r_{n+1} given channel state s_n , and C is the cost associated with the change in rate, where $C < 0$.

5. The method of Claim 4 further comprising selecting the rate r_{n+1} that satisfies the respective optimal cost function for each of the one or more remote communication terminals as the respective optimal one of the plurality of rates to be used by the first communication terminal for the
5 respective subsequent signal, where r_{n+1} is given by:

$$r_{n+1} = \arg \max_u \{R(s_n, r_n, u) + \beta V_{n-1}(s_n, u)\}.$$

6. The method of Claim 1 further comprising establishing the
10 respective forward channel and a respective reverse channel between the first communication terminal and each of the one or more remote communication terminals.

7. The method of Claim 1 further comprising determining the
15 respective channel state of the respective forward channel between the first communication terminal and each of the one or more remote communication terminals, the respective channel state based upon a respective measured signal-to-interference ratio corresponding to the respective received signal.

8. The method of Claim 1 further comprising transmitting a
20 respective rate update message to the first communication terminal from each of the one or more remote communication terminals, each respective rate update message indicating the respective optimal one of the plurality of rates to be used by the first communication terminal for the respective subsequent
25 signal.

9. The method of Claim 1 further comprising saving the
respective optimal one of the plurality of rates to be used by the first
communication terminal for the respective subsequent signal in memory.

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10. The method of Claim 1 wherein the determining step is performed at each of the one or more remote communication terminals.

5 11. A rate control device for controlling the rate for communications from a first communication terminal to a second communication terminal of a communication system comprising:
a rate control module configured to perform the following steps:
obtaining a respective one of a plurality of rates
corresponding to a signal received over a forward channel from the first
10 communication terminal, the received signal having been modulated using the respective one of the plurality of rates, wherein each communication terminal is capable of supporting communications using the plurality of rates;
obtaining a channel state corresponding to the channel conditions of the forward channel for the signal received; and
15 determining an optimal one of the plurality of rates to be used by the first communication terminal for a subsequent signal to be transmitted to the second communication terminal based upon a maximization of the throughput to the second communication terminal given the channel state of the forward channel and a cost associated with a change
20 in rate.

25 12. The device of Claim 11 further comprising an integrated circuit device, the rate control module implemented within the integrated circuit device.

13. The device of Claim 11 wherein the determining step to be performed by the rate control module comprises:
determining, for the determining the optimal one step, cost
functions corresponding to selecting each of the plurality of rates for the
30 subsequent signal given the received signal using the respective one of the

plurality of rates, each of the cost functions being a function of the throughput to the second communication terminal and a cost associated with the change in rate; and

5 selecting, for the determining the optimal one step, an optimal cost function from the cost functions, the optimal cost function providing the optimal one of the plurality of rates to be used by the first communication terminal for the subsequent signal to be transmitted by the first communication terminal.

10 14. The device of Claim 13 wherein the determining, for the determining the optimal one step, the cost functions step to be performed by the rate control module comprises:

15 determining, for the determining the optimal one step, cost functions associated with arriving at a system state using the respective one of the plurality of rates from previous system states using each of the plurality of rates, each of the cost functions being a function of the throughput to the second remote communication terminal and the cost associated with the change in rate; and

20 wherein the selecting, for the determining the optimal one step, the optimal cost function comprises:

selecting, for the determining the optimal one step, the optimal cost function from the cost functions, the optimal cost function providing an optimal one of the plurality of rates used in arriving to the system state using the respective one of the plurality of rates; and

25 equating the optimal one of the plurality of rates used in arriving to the system state to the optimal one of the plurality of rates to be used by the first communication terminal for the subsequent signal.

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15. The device of Claim 13 wherein the rate control module is configured to perform the following additional step:

solving the following equation to perform the determining, for the determining the optimal one step, the cost function step and the selecting,
5 for the determining the optimal one step, the optimal cost function step:

$$V_n(s_n, r_n) = \max_{u \in \{1, 2, \dots, L\}} \{R(s_n, r_n, u) + \beta V_{n-1}(s_n, u)\}$$

where $V_n(s_n, r_n)$ is the optimal cost function for the n^{th} iteration, s_n is a current
10 channel state of the forward channel corresponding to the received signal, r_n is the respective one of the plurality of L rates that the received signal is modulated with, u assumes any possible value of the plurality of L rates for the rate r_{n+1} , r_{n+1} is the optimal one of the plurality of L rates to be used by the first communication terminal for the subsequent signal, β is a discount factor,
15 $V_{n-1}(s_n, u)$ is the optimal cost function for iteration $n-1$, and $R(s_n, r_n, u)$ is a cost-per-stage function given by:

$$R(s_n, r_n, u) = \begin{cases} T(r_n, s_n) & \text{if } u = r_n \\ C + T(u, s_n) & \text{if } u \neq r_n \end{cases}$$

20 where $T(r_n, s_n)$ is the throughput to the second communication terminal when rate r_n is used for r_{n+1} given channel state s_n , $T(u, s_n)$ is the throughput to the second communication terminal when rate u is used for r_{n+1} given channel state s_n , and C is the cost associated with the change in rate, where $C < 0$.

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16. The device of Claim 15 wherein the rate control module is configured to perform the following additional step:

selecting the rate r_{n+1} that satisfies the optimal cost function for the second communication terminal as the optimal one of the plurality of rates to be used by the first communication terminal for the subsequent signal,
5 where r_{n+1} is given by:

$$r_{n+1} = \arg \max_u \{R(s_n, r_n, u) + \beta V_{n-1}(s_n, u)\}.$$

10 17. The device of Claim 11 further comprising a state determination module coupled to the rate control module and configured to perform the following step:

determining the channel state of the forward channel between the first communication terminal and the second communication terminal, the channel state based upon a measured signal-to-interference ratio
15 corresponding to the received signal.

18. The device of Claim 11 further comprising a receiver of the second communication terminal and configured to perform the following
20 step:

receiving the received signal from the first communication terminal via the forward channel.

19. The device of Claim 11 further comprising a transmitter
25 coupled to the rate control module and configured to perform, the following step:

transmitting a respective rate update message to the first communication terminal, the rate update message indicating the optimal one of the plurality of rates to be used by the first communication terminal for the
30 subsequent signal.

20. The device of Claim 11 wherein the rate control module is located at the second communication terminal.

5 21. A method of rate control between a first communication terminal and a second communication terminal of a communication system, the method comprising:

 obtaining a respective one of a plurality of rates corresponding to a signal received over a forward channel from the first communication
10 terminal, the received signal having been modulated using the respective one of the plurality of rates, wherein each communication terminal is capable of supporting communications using the plurality of rates;

 obtaining a channel state corresponding to the channel conditions of the forward channel for the signal received; and
15 determining an optimal one of the plurality of rates to be used by the first communication terminal for a subsequent signal to be transmitted to the second communication terminal based upon a maximization of the throughput to the second communication terminal given the channel state of the forward channel and a cost associated with a change in rate.

20 22. The method of Claim 21 further comprising receiving, at the second communication terminal, the signal having been modulated with the respective one of the plurality of rates from the first communication terminal via the forward channel.

25 23. A rate control system between a first communication terminal and a second communication terminal, the system comprising:

 means for receiving, at each of the one or more remote communication terminals, a respective signal modulated using a respective
30 one of a plurality of rates from the first communication terminal via a

respective forward channel, wherein each communication terminal is capable of supporting communications using the plurality of rates; and

- means for determining a respective optimal one of the plurality of rates to be used by the first communication terminal for a respective
- 5 subsequent signal to be transmitted to each of the one or more remote communication terminals based upon a respective maximization of the throughput to each of the one or more remote communication terminals given a respective channel state of each respective forward channel and a cost associated with a change in rate.

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11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000